Up-Front Design Impacts on Operations Cost Reduction in the JPL Advanced Projects Design Team

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‘l’he Jet Propulsion Laboratory has assembled a group of experienced mission and spacecraft designers to serve as a core team for quick response to a wide range of advanced mission study requests. Known as the Advanced Projects Design Team, or “Team X,” these engineers represent the disciplines necessary to establish the feasibility of a new mission concept, including science planning, spacecraft and instrument design, mission analysis, spacecraft system engineering, mission operations system engineering, and cost analysis. New mission concepts coming out of JPL **pass through Team X before they are presented to p 0-tential sponsors.**

The Ground Systems & Mission Operations position on Team X is responsible for design of ground data systems, staffing plans for mission operations teams, and development of the preliminary data acquisition and return strategy for the proposed mission. Reductions in operations costs compared with traditional systems is a major focus of this position. Such reductions are achieved by a variety of system engineering methods: influencing design of the spacecraft itself to make it easier t o operate, such as large margins in onboard data storage and telemetry capacity; use of improved onboard computing resources, both hardware and software; establishment of firm project-level operating guidelines; use of fee-for-service arrangements with existing ground system infrastructures; and small operations team size.

This paper provides an **overview of the workings** of Team X, **a** discus**sion of the system engineering methods** used by the Ground Systems **position, and a justification of tbe belief that operations costs are best reduced by including operations issues early in the design process.**

Introduction

The current NASA Administrator has made reduction of operations costs a prime focus of the agency. His directive to lower these costs addresses a symptom of a larger problem, namely that operational issues tend to be an afterthought in the design process.

We assert that the best way to reduce operations costs is to consider operational issues early in the design process, of equal rank with spacecraft and trajectory design issues. Such forethought will lead to missions which are easier to operate, and therefore cheaper.

Not only is this an attractive option for operations costs, but for the entire mission lifecycle cost as well. NASA has recently directed that all costs associated with a given mission be accounted for in the mission’s lifecycle cost. Infrastructure costs that in the past were accounted for under various NASA operating budgets must be prorated toward each project which uses them.

For mission concepts in pre-Phase A studies, a concurrent engineering mechanism developed at the Jet Propulsion Laboratory (JPL) can be used to aid this lifecycle design process. Called the Advanced Projects Design Team, or "Team X," this mechanism has specific benefits for operations designers and can result in lower operations costs. The first part of this paper describes this mechanism, the second describes up-front design methodologies for reducing lifecycle cost, and the third makes some observations about today’s environment.

Team X: A Mechanism for Up-Front Design

JPL has assembled a group of experienced mission and spacecraft designers to serve as a core team for quick response to a wide range of advanced mission study requests. Known as the Advanced Projects Design Team, or "Team X," these engineers represent the disciplines necessary to establish the feasibility of a new mission concept, including science planning, spacecraft and instrument design, mission analysis, spacecraft system engineering, mission operations system engineering, and cost analysis.

Team X was created to improve both the quality and the speed-of-generation of advanced mission concepts; to develop mission generalists from a pool of experienced engineers; and to create a reusable study process with dedicated facilities, equipment, procedures, and tools. New mission concepts coming out of JPL pass through Team X before they are presented to potential sponsors.

Team X is comprised of the 15 positions shown in Figure 1. Individuals are assigned to these positions on a full-time basis and are responsible for assuring that the designs presented or solutions proposed reasonably reflect the concerns and constraints of their areas.

The Process

A customer, typically a proposal manager or study leader, brings Team X a mission concept, for which he specifies his science goals and any relevant mission parameters. A study is done for the customer over three half-day sessions: the first day is spent describing the mission to Team X and developing any relevant guidelines; the second is spent on design; and the third completes the design and adds a cost estimate. Additional time can be spent iterating cost against performance. While the steps in the process vary somewhat from study to study, a general outline of the design process is given in Table 1.

The study is done interactively in the facility shown in Figure 1, using linked software between the various Team X member stations and display hardware which can project information from any monitor to one of several screens for viewing by the entire team.

The Products

The one-week activity described above produces a 30-40 page report which contains 1) an end-to-end data acquisition strategy for the mission, including mission design and operational issues; 2) a spacecraft description, including mass and power estimates, subsystem descriptions, and an initial spacecraft configuration; 3) recommendations for a launch vehicle and which (if any) commercially available spacecraft best meet the mission requirements; and 4) a detailed cost and schedule for development and operations.

Ground Systems & Mission Operations Element

The Ground Systems & Mission Operations element on Team X has four primary responsibilities: 1) development of initial data acquisition and return strategies; 2) initial design of ground data systems; 3) development of staffing plans for mission operations teams; and 4) cost estimation for both MOS development and operations.

Reductions in operations costs compared with traditional systems is a major focus of this position. Such reductions are achieved by a variety of system engineering methods: influencing design of the spacecraft itself to make it easier to operate, such as large margins in onboard data storage and telemetry capacity; usc of improved onboard computing resources, both hardware and software; establishment of firm project-level operating guidelines; usc of fee-for-service arrangements with existing ground system infrastructures; and a small operations team size.

Cost Reduction Methodologies

Influencing Spacecraft Design

One method of reducing costs is to influence design of the spacecraft to make it easier to operate. An example is the Chemistry and Circulation Occultation Spectroscopy Mission (CCOSM), a proposed mission to measure tropospheric and stratospheric trace molecules. The CCOSM team was attempting to define spacecraft requirements for the downlink rate and had a baseline using an S-band system at 2 Mbps. Team X suggested considering an X-band system at 20 Mbps, where the project would spend more money up-front on the spacecraft, but would save overall, due to a reduction in tracking costs. Team X performed an analysis to determine a data return strategy for both options, specifically deriving how many downlinks per day would be needed (Figure 2). Then, based on this analysis, a comparison of mission lifecycle costs (Table 2) was generated. The results showed that the "more expensive" X-band system was actually cheaper across the mission lifecycle, as well as simpler to operate since the scheduled number of downlinks dropped dramatically. Other cases have existed where the cost difference is negligible, but the project agreed to accept the higher data-rate solution, simply because it would be easier to operate.

Improved Onboard Computing Resources

Another method involves the use of improved, onboard-computing resources. Spacecraft computing components are available now with considerably increased capacity and lower cost than in the past. Increased use of on-board computational margins and modern operating systems allow on-board resource management and reduce the need for ground-bad analysis, memory management, and data processing. Also, advances in solid state recorder technology have eliminated the need to fly tape recorders, which are notoriously difficult to operate.

The LightSAR mission, an earth-orbiting, synthetic aperture radar platform designed for multi-disciplinary radar studies, provides an example. Recent advances in solid-state recorder technology enabled Team X to recommend three times the originally-planned solid-state data storage. This recommendation served to simplify operations by reducing the need for complex management of on-board data and tracking-station scheduling.

Firm Observation Guidelines

The project can also establish firm implementation guidelines for its development phase. This helps greatly to forestall "creeping requirements" which can cause development and operations costs to increase. [1,2] For example, the Shuttle Radar Topography Mission (SRTM) intentionally decided to reduce the kinds of science investigations it would allow to reduce development, test and operations cost. Team X frequently recommends that science users define foeused science goals and operational guidelines so that optimized designs can be created.

use of Communication Standards and Commercial Services

The use of communication standards offer excellent cost saving opportunities. These standards allow amortized development costs, as well as better understood designs with fewer surprises. An example of their usc in the operations theater is the transfer of the mission operations for the British STRV 1A and 1 B spacecraft to the University of Colorado. The spacecraft are CCSDS compatible and the cost to transfer operations was less than $200K.

The use of open communication standards also facilitates the use of services offered by commercial providers. An example of how costs can be reduced by using commercial services is seen on the recent CloudSat proposal, a cloud distribution and composition mission. This mission selected a Lockheed-Martin corporate asset (which incorporates open standards) to provide both their mission operations and tracking services and was able to show a significant cost reduction in their projected operations costs.

Reduced Operations Team Size

Using these and other up-front, systcm-engineering techniques lead to more easily operable spacecraft, which enables significantly smaller operations teams. Reducing the need for large operations teams in this fashion probably has the most significant impact on the reduction of operations costs and is a direct result of better up-front design. As an example, a recent concept study was done for NASA HQ to assess the impacts of improved spacecraft technologies, Using the Galileo mission as an example, Team X did a re-design which duplicated the science goals of the now 20-year old mission using advances in spacecraft and instrument components and up-front design techniques. We estimate that these improvements would allow for an 80% reduction *in* size of the operations team.

Observations

In the last year, Team X has performed **74 advanced** mission studies. Reviewing this wide variety of both planetary, Earth-based, and astronomical studies, wc have identified two trends which apply to operations and operations cost reduction.

Lifecycle Concept Development is Required for New Missions

In order to win new missions, organizations should remember that funding agencies now require more complete concept descriptions for the lifecycle of the mission. Mission and study managers are increasingly required to describe, defend, and cost their mission concepts to a higher level of detail, earlier in the development process and in a much more competitive environment than ever before. LifeCycle costs and concepts must be fully described and should include data acquisition strategies, ground system designs, operations infrastructure utilization, operations costs and data analysis costs. Details which used to be required 1-2 years after the project was selected are *now* required in the proposal.

Focused Selection of Advanced Technology

In the numerous studies **which have come through** Team X, a practical guideline for the selection and use of an advanced technology item has emerged:

> "Does the proposed technology either a.) achieve a mission objective that cannot be **achieved without it; or b.) save the project a substantial amount of money?"**

If there is not a strong "yes" answer to at least one of these questions, then typically the technology will not be of interest to missions. Technology developers should focus their research in this manner, so what they are developing **will be sought after by potential mission customers. This focus will rd-**low for the early adoption of the technology item, which gives the developer the opportunity to **influence the design so that he can easily integrate his solution into the project.**

Conclusions

The temptation when presenting such a paper is to focus on the mechanism, *in* this case Team X, and to overlook the concept. The concept wc wish to leave with the reader is that if one is serious about reducing operations costs, one must make operations issues a fundamental part of the design process from the beginning of the project. The lifecycle cost advantages to developing an easy-to-operate, well-defined mission should not be underestimated. While not the answer for implementing all aspects of this concept, the Team X mechanism has had success in positively effecting start-up projects to perform their designs with operations issues in mind.

Acknowledgments

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References

[1] Rekey, M. J., and S. D. Wall, "Effects on Operations of Highly Adaptive Missions", *Journal of Spacecraft and Rockets,* Vol. 33, No. 2, March-April 1996, pp *298-304.*

[2] Wall, S. D., and Ledbetter, K. W., *Design of Mission Operations Systems for Scientific Remote Sensing,* Taylor and Francis, London, 1991, pp 149-151.

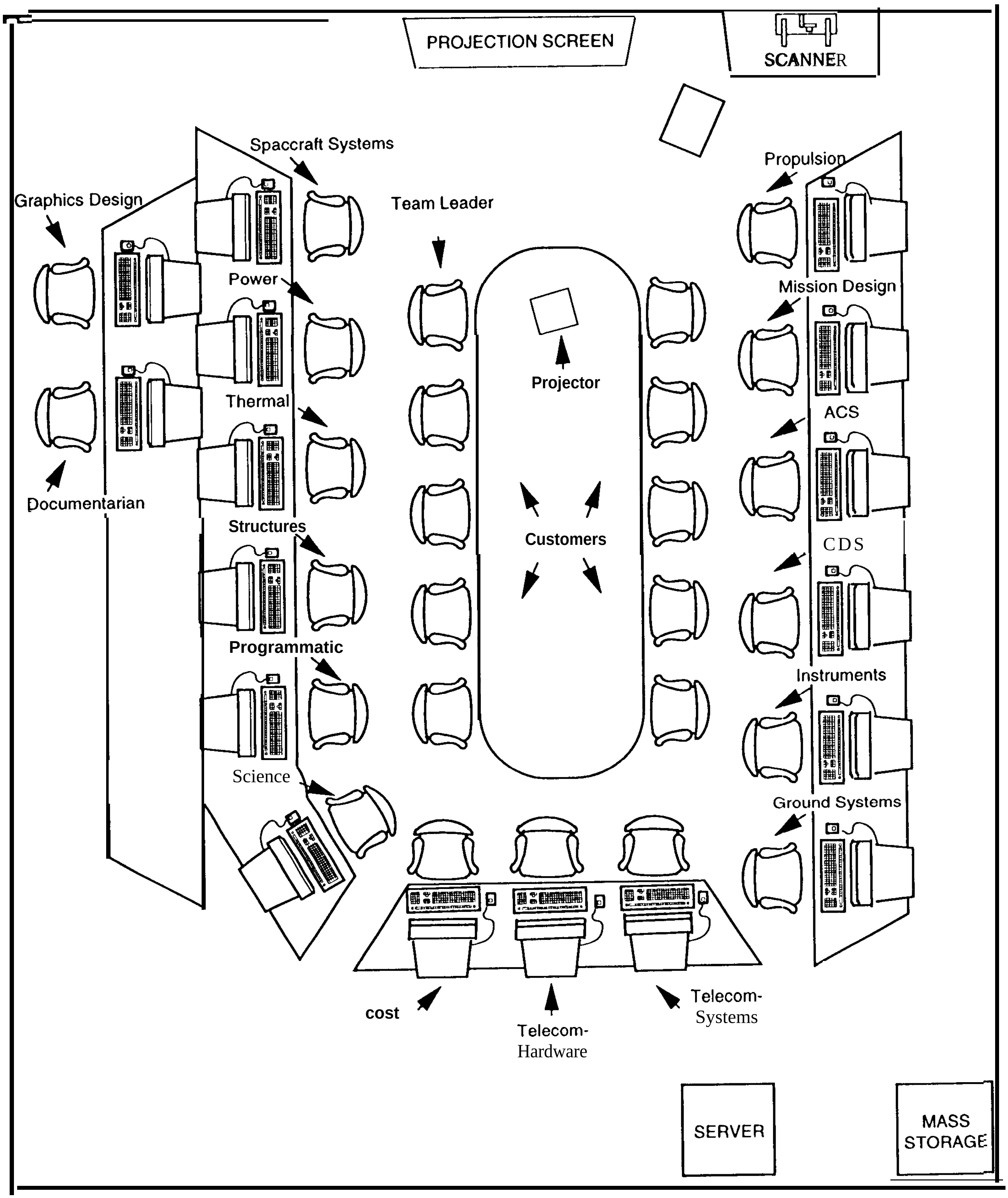
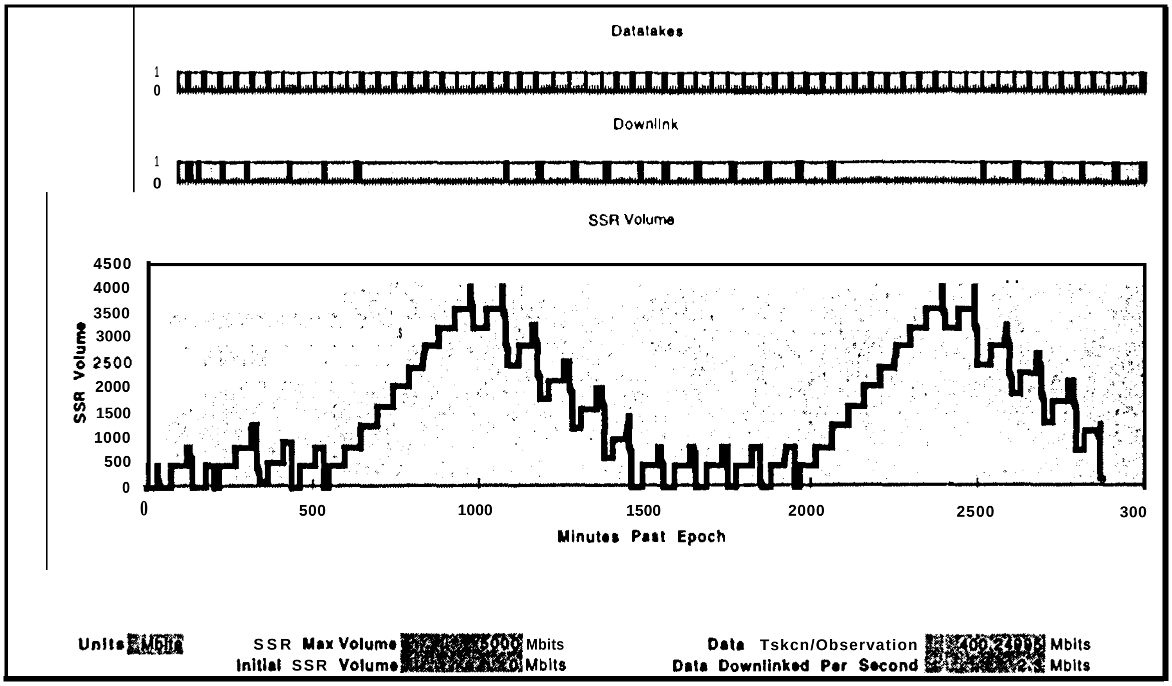


Figure 1. Team X is comprised of the Team Leader and the following 15 positions: Propulsion, Mission Design, Attitude Control, Command & Data Handling, Instruments, Ground Systems and Mission Operations, Telecom-Systems, Telecom-Hardware, Cost, Science, Programmatic, Structures, Thermal, Power, and Spacecraft Systems. Design sessions are done interactively with computer-based tools and support personnel.



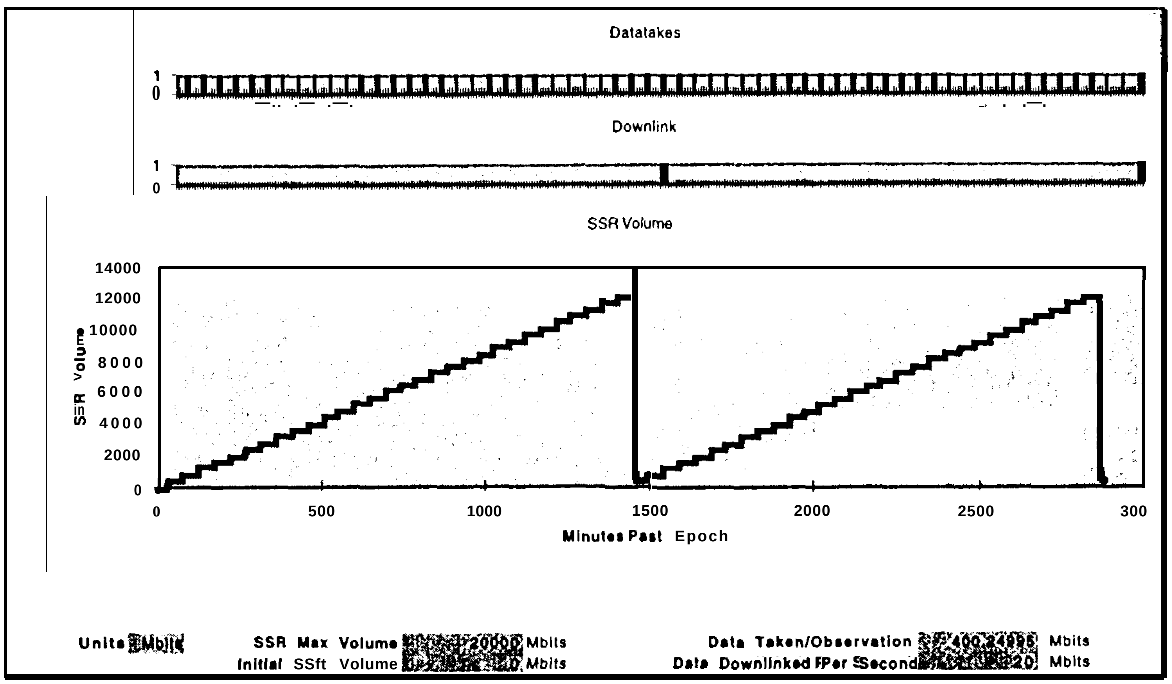


Figure 2. CCOSM Data Return Strategy Options. Orbit analyses of the form above were done for CCOSM, where data collection and return is shown over two days in the upper chart at 2 Mbps S-band downlink and in the lower chart at 20 Mbps X-band downlink. Increases in slope indicate data is being taken and sharp decreases show data being downlinked.

Table 1. Team X Study Flow

Study Leader:	Description to Customer of Team X process, tools, products, summary of task at hand
Customer:	Study objective, ground rules, science
Science:	Detailed exposure to science and mission
Instruments:	Selected instruments with mass, power, data rates
Mission Design:	Trajectory, launch vehicle and allowable mass, viewing, and navigation
Study Leader:	Group discussion of applicable technologies
Ground System:	Data acquisition strategies, ground stations, operations concept, on-board storage requirements, downlink rates
cost:	First cut at costing ground rules and schedule
Systems:	Summary so far, ground rules, pointing requirements, radiation requirements, power mode definitions
Telecomm:	Design, antenna/amplifier size, pointing requirements (if exceeds instrument), mass, power
ACS :	Design, mass, power
CDS:	Design, mass, power, software cost
Systems:	Mass, power summary so far
Power:	Design, mass, power
Propulsion:	Design, probable mass, power
Structure:	Design, probable mass, power, mechanisms, configuration drawing
Thermal:	Design, mass, power
Systems:	Mass, power summary
cost:	Collect and iterate

Table 2. CCOSM Data Return Costing Comparison

	S-band Downlink to 3 LEO-Ts (I downlink/ orbit)	S-band Downlink to 3 Stations (t downlink/ orbit)	Lo-Rate X-band Downlink to LEO-T, 1 pass/day	Lo-Rate X-band Dowrdink to Existing Station, 1 pass/day
CDS	110	110	220	220
Telecom	**2600**	**2600**	4000	4000
Ground System One-Time Purchases				
Station Purchase	6000	0	2000	0
Ground System Ops Costs (3 years)				
Station Fees	o	**16425**	0	1095
Related Institutional Workforce	0	600	0	600
Station Staffing	600	0	**600**	0
Increased Data Handling	1200	1200	0	0
Increased Station Coordination	600	**600**	0	0
TOTAL SK (Includes 3 Yrs. Of Ops)	11110	21535	6820	5915